6" GaAs lower-cost than Si for high-performance ICs

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A significant part of the European Microwave week held in Munich last October was the event Gallium Arsenide and other semiconductor Applications Symposium (GAAS'99). This comprised two full days of contributed and invited presentations followed by a full day of short courses with a high number of participants.

In the opening session of GAAS'99, Charles Huang of Anadigics Inc addressed the important issues of opto-electronic applications for Gigabit Ethernet. The key point was that this market is expected to grow at a phenomenal 45%-plus annual rate for the next five years and that III-V technologies are expected to dominate for front-end ICs (optical wavelength sources, detectors, transimpedance amplifiers, laser drivers, etc).

This III-V dominance will be maintained because a direct bandgap is hard to beat for photon interactions. However, horizontal integration must take place to lower costs and improve bandwidth, i.e. the technology must evolve so that optoelectronic devices and transistors are placed on the same chip.

Marc Rocchi of PML highlighted the last 10 years of III-V foundry services, their role, the processes offered, customer support, and CAD tools. The second plenary session addressed millimetre-wave integrated circuit (MMIC) packaging for the consumer market. The importance of surface mount packaging and optimised via technology was emphasised.

The focused session on "Military and Space Applications" attracted many delegates. M.C. Comparini of Alenia Aerospazio described work supported by ESA/ESTEC, the aim of which was to develop a set of MMICs to be used for Ka-band telecommunication satellite payloads. The MMICs have been designed by Alenia and UMS; UMS (which has a 0.25 μm PHEMT process) was the selected foundry. The paper demonstrated that this technology is ready to be used in space equipment, having excellent performance and reliability.

A paper by A. Darbandi of Alcatel Space Industries concerned the development of a highly capable L-band SSPA at Alcatel Space Industries. All the design steps have been extensively covered and compared with the performance achieved. One can note an output power of 43.8 dBm at 1.5 GHz with an efficiency greater than 60%. The modules make use of HFET technology, and have been the basis of space programs like MT-Sat.

On the one hand silicon, possibly jointly with germanium to form the heterojuction SiGe, is now entering the microwave field very strongly. SiGe HBT technology was described by Moeller from the Infineon laboratories, where speeds adequate for 40 Gbit/sec operation have been observed. Kasper of Stuttgart University described how the future might see 200 GHz current gain bandwidth from SiGe HBTs with low breakdown voltage. A symmetrical CMOS technology using silicon and germanium was described as being in the early research stage.

The Si versus III-V competition also appeared in several sessions. Deyhimy of Vitesse presented a success story for ion-implanted GaAs MESFETs in fibre-optic data transmission systems where the more-than-adequate speed coupled with the lower-than-silicon costs of the ion-implanted MESFET has captured the market.

However, the most significant results now appear with wide-bandgap semiconductors such as GaN, AlN, InN and SiC. This is particularly relevant for microwave power generation, with the semiconductor operating at strongly elevated temperatures. John Zolper of the ONR presented the key address on this topic. His theme was that such remarkable progress had been made in the last four years that, if it continued at the same pace, nitride power amplifiers would soon capture a substantial proportion of military and commercial power amplifier applications. Substantial challenges remain, however, even for the lower frequencies, especially in terms of scaling GaN HEMT devices to larger sizes and powers. Silicon carbide MESFETs provide the same high-voltage efficient operation for frequencies below 6 GHz, but the nitride materials need further work to make larger devices.

Another interesting session focused on "GaAs-related EU-supported projects". Stephen Bland of Epitaxial Products, UK described work on materials for GaInP/GaAs HBTs within the GAMMA project. Ladbrooke of GaAs Code Ltd, UK described FET physics-based MMIC yield analysis CAD tools and capabilities demonstrated within the EDGE project. Olivier Vendier of Alcatel Space presented work on HBT technology and reliability for satellite applications, within the relatively new APOS project. Finally Camiade of UMS presented the mm-wave front-end developed within the on-going AWARE/LOCOMOTIVE projects for automotive applications at 77GHz.

Speakers in various sessions pointed out the importance of growth techniques. Several advantages of metallorganic vapour phase epitaxy (MOVPE) over other epitaxial growth technologies were presented by Heuken of Aixtron. The main advantages are: extreme uniformity of layer thickness, doping and composition; low defect density; and highly efficient utilisation of the precursor.

Yohei Otoki of Hitachi Cable presented the mass-production technique of bulk crystal growth, making substrates, and epitaxial growth for large-size wafers. Mass production of microwave ICs should be supported by high-volume manufacturing of semi-insulating substrates and epitaxial wafers with good crystal quality, good uniformity over the wafer, and good reproducibility. The demand for large-size wafers (of 125 mm and 150 mm diameter) is also increasing rapidly. Hitachi Cable has successfully developed a state-of- the-art mass-production line for 150 mm semi-insulating wafers with the capability of producing up to 15,000 wafers a month. The advances made for this line are:

(1) A very large crystal puller to be loaded with up to 50 kg of GaAs raw material in a very large (16") pBN crucible: The pullers grow "huge" 300 mm long 150 mm diameter semi-insulating ingots (Figure 1), with basic electrical properties and uniformity proven comparable to commercial 100 mm wafers.

(2) The new vertical-type furnace for three-step boule annealing under an arsenic atmosphere: The conventional horizontal method cannot be used due to the weight of the ingot.

(3) Fully-automated polishing line: including a wafer mounter that can accommodate five 150 mm wafers on each 480 mm alumina plate, and a robotic hand which aids the one-side polisher and wafer rinsing machine.

(4) All of the inspection and evaluation machines are designed and/or remodelled for the full 150 mm wafer area: automatic EPD counter, flatness tester, particle counter, "Makyou" image processor for inspecting local thickness variation, EL2 measurer, and the heavy-metal inspection system by TXRF (total reflection X-ray fluorescence).

These 150 mm substrates are already in mass production and used for GaAs high-speed devices and power transistors fabricated using ion implantation. Demand for 150 mm wafers will dramatically increase in 2000, not only for ion-implanted applications but also for epitaxial substrates.

A 150 mm diameter mass-production line has already been established (8,000 epi-wafers per month, rising to 16,000 this year) using the original design of face-down horizontal MOVPE reactors. These have realised very good uniformity across the wafer and excellent reproducibility with high throughput. The advances made with this system are:

(1) smooth reactive gas flow with uniform and stable growth;

(2) a very simple structure.

These reactors can be applied to multi-epitaxial growth of larger-size wafers without any other change to the reactor system, except for just exchanging the susceptor. Many epitaxial layers grown by this method have been evaluated and found to be comparable with the same quality of 100 mm wafers. Some of these large epi-wafers have already been qualified by device makers.

AIXTRON and EMCORE also presented large-size epitaxial systems with good results. Mass production of GaAs devices in large volumes using the large epitaxial wafer is surely going to be at the realistic stage in 2000. Seemingly, large-size epi-wafers and substrates (rather than 100 mm wafers) will be mainstream worldwide within two or three years, much earlier than previously anticipated.

The closing session addressed the challenge of SiGe and CMOS silicon to all IC applications of GaAs. The picture that emerged is that the market for III-V ICs is growing robustly, a statement particularly true

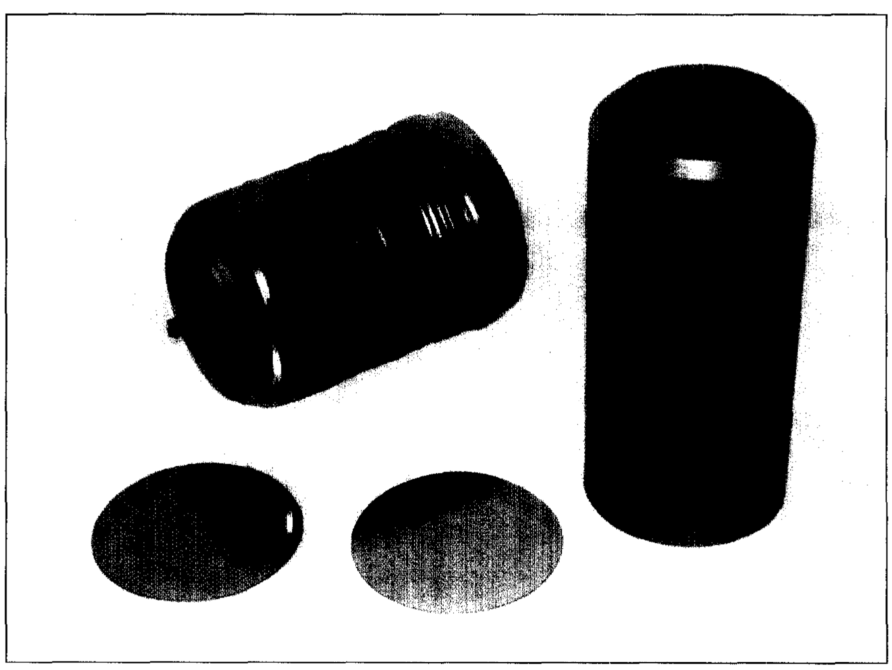

Figure 1: 150 mm diameter GaAs ingots and wafers (Hitachi Cable, Japan).

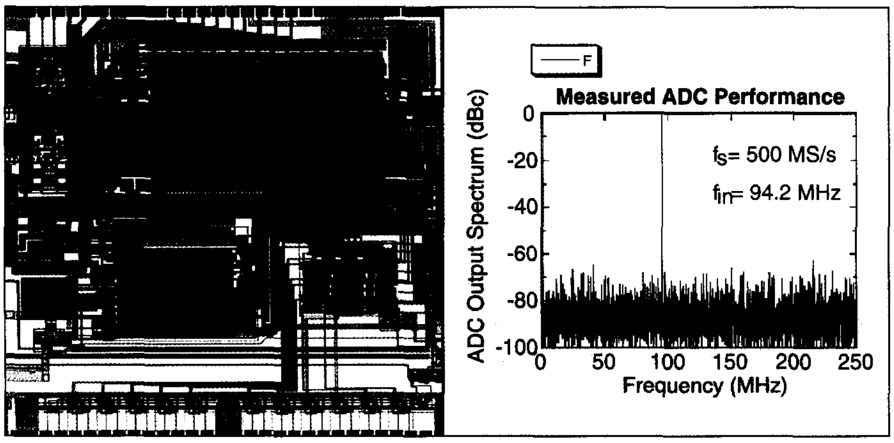

Figure 2: An RSC GaAs HBT/Diode Analog-to-Digital Converter (Rockwell Science Center).

for power amplifiers at all frequencies. The growth rate is expected to be 20% for analogue and microwave ICs and 26% for digital/mixed-mode ICs. It is only in the latter category (digital/mixed- mode ICs) that serious incursions will come from silicon CMOS and SiGe HBTs. Where power either is or must be low, the speed of the silicon technologies will be adequate to take some market share from incumbent III-V technologies. However, applications requiring high Early voltage, the highest speed, or a breakdown voltage greater than 3 Volts will require III-V HBT devices.

Figure 2 illustrates a typical example of such an IC. It is an ADC from Rockwell Science Center which provides an effective number of 9 bits at a sample rate of 1Gbit/sec. The evolution of communications systems will be paced by a growing availability of chips like this at low cost. The costs of GaAs HBT technology are expected to be as low as (or lower than) those of silicon BJTs and BiCMOS, especially as more GaAs fabrication is accomplished on 150 mm wafers.

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